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BULLETIN

OF

The Terrestrial Electric Observatory

OF

FERNANDO SANFORD
Palo Alto, California

VOLUME V

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Observations on Solar and Lunar Diurnal Variations of Earth Potential Due to Changes in Distribution of the Earth's Surface Charge, Including Two New Methods of Recording Such Variations, and on the Accompanying Variations in the Atmospheric Potential Gradient for the Year 1927

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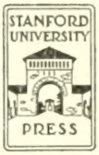
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OBSERVATIONS ON SOLAR AND LUNAR DIURNAL VARIATIONS OF EARTH POTENTIAL DUE TO CHANGES IN DISTRIBUTION OF THE EARTH'S SURFACE CHARGE, INCLUDING TWO NEW METHODS OF RECORDING SUCH VARIATIONS, AND ON THE ACCOMPANYING VARIATIONS IN THE ATMOSPHERIC POTENTIAL GRADIENT FOR THE YEAR 1927

Variation in the distribution of the earth's surface charge for the year 1927.—During the year 1927 records of the diurnal variation of the intensity of the earth's surface charge at Palo Alto were obtained for 337 days, and records of the diurnal variation of the air-potential gradient were obtained for 332 days.

The recorded variations of the earth potential at this station were more irregular than in most previous years. The method of measuring this variation has been described in the earlier volumes of this *Bulletin*. Briefly, a quadrant electrometer was enclosed in an earthed wire cage. One quadrant pair was connected to this cage, and through it to the water system of Palo Alto. The other quadrant pair was connected to an insulated conductor inside the cage, which conductor was discharged to the earth at the beginning of the experiment. The needle was charged from a battery of 200 dry cells, which was inside a metal-lined box inside of, and grounded to, the wire cage, and one pole of the battery was grounded to this box and to the water system. The sensitivity of the electrometer was such that a single dry cell introduced between the electrometer case, to which the earthed quadrants were attached, and the enclosing cage gave a deflection of about 13 centimeters on the record sheet. The deflections of the electrometer were recorded photographically on a drum outside the cage.

(Since the close of the year two more sensitive methods of recording these variations, both of which are free from the theoretical objections which have been urged against the method here described, have been devised and will be described later in these pages.)

The photographic record was measured to one millimeter, and the monthly average for each hour of the day was computed to 0.1 mm. the average diurnal variation in tenths of millimeters for the different months of the year is shown in Table I (p. 6).

It may be seen from Table I that the daily range of electrometer deflection varied greatly in different months, and that it was greatest at the equinoxes and least at the solstices.

The irregularities of the daily ranges in a given month are considerable, owing to the fact that all days, no matter how much disturbed so long as the

TABLE I

Monthly Averages of Daily Variation of Earth Potential in Tenths of Millimeters on the Photographic Record for the Year 1927

A.M.	1	2	3	4	5	6	7	8	9	10	11	Noon
January	+ 6	+ 6	+ 7	+ 7	+ 8	+ 7	+ 7	+ 8	+12	— 2	— 4	—14
February	+ 9	+11	+12	+11	+12	+11	+16	+14	+16	— 4	—30	—22
March	+30	+31	+32	+30	+33	+35	+35	+28	+36	—14	—41	—51
April	+26	+36	+43	+48	+51	+60	+64	+51	+22	+13	— 8	—30
May	+26	+27	+26	+23	+22	+21	0	—32	—42	—44	—34	—26
June	+12	+11	+ 9	+ 7	+ 7	+ 8	+ 8	—14	—31	—36	—23	— 7
July	+10	+ 6	+ 1	— 7	—12	—17	—21	—17	— 8	— 9	—11	— 9
August	+11	+14	+15	+14	+12	+10	+13	+ 5	— 7	—10	— 7	— 2
September	—15	—20	—28	—33	—38	—45	—43	—35	—18	— 9	— 3	+ 6
October	— 6	—10	—15	—18	—21	—24	—24	—13	—20	—45	—26	— 3
November	+14	+ 9	+ 6	0	— 9	—10	—15	—12	—22	—72	—65	—40
December	+ 9	+12	+14	+16	+18	+22	+23	+35	+33	—13	— 3	+ 1

P.M.	1	2	3	4	5	6	7	8	9	10	11	Mt.
January	—27	—22	—22	—17	—11	0	+ 4	+ 6	+ 8	+ 6	+ 7	+ 7
February	— 6	— 6	—13	—10	—10	— 7	— 3	0	— 1	+ 1	+ 4	+ 5
March	—60	—62	—52	—50	—36	—18	— 6	+ 7	+17	+20	+23	+28
April	—32	—51	—76	—70	—62	—53	—43	—29	—10	+ 3	+18	+21
May	—20	—24	—21	— 3	— 8	— 6	+ 8	+17	+19	+17	+21	+25
June	0	+ 6	+ 7	+ 9	+ 7	+ 2	— 6	— 6	+ 7	+10	+15	+17
July	— 7	— 7	— 1	+ 1	+ 7	+12	+18	+14	+11	+12	+16	+13
August	— 2	— 2	— 2	+ 2	+ 1	— 6	—22	—26	—21	— 9	+ 3	+ 9
September	+17	+41	+63	+55	+53	+41	+26	+15	+ 6	— 1	— 7	—12
October	+25	+43	+49	+47	+32	+ 4	+ 2	+ 3	+ 3	+ 4	+ 3	+ 1
November	—10	+ 5	+16	+22	+23	+22	+25	+25	+25	+23	+19	+17
December	—10	—21	—25	—26	—22	—19	—17	—14	— 7	— 4	+ 1	+ 5

record was measurable, were used in computing the average. Thus while the range in the average curve for the year was but 4.3 mm. there were days where the range was many times this great, one of them (April 16) having a range of 71 mm. and another of 56 mm. There were a few days in which the records went off the sheet and could not be measured.

The average daily variation of earth potential is shown by the continuous curve in Figure 1.

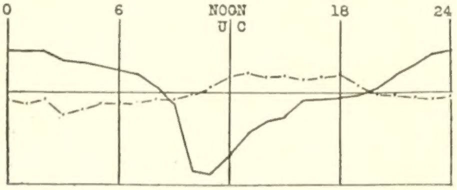

FIGURE 1

Solar and lunar daily variation of earth potential at Palo Alto for the year 1927. The continuous curve indicates the solar and the dashed curve the lunar variation.

Average lunar diurnal variation of earth potential for 12 synodic periods of 1927.—From the 337 days for which the variation of earth charge at Palo Alto was measured it was possible to determine the lunar daily variation for approximately 12 synodic months corresponding to the calendar months. None of these synodic months was wholly complete, four of them consisting of 28 days and only two having as few as 24 days.

The method used was to locate the position in its lunar day of every measured hour of the year, taking the hour nearest the upper culmination of the moon as the mid-hour of the day. Three hundred twenty lunar days were arranged in this way and assigned to their respective synodic periods. Table II gives the mean diurnal variation for each of these synodic periods. The month name in the first column is the one which corresponds most nearly with the synodic period under consideration. The hourly deflections are given in hundredths of millimeters, instead of in tenths, as in Table I.

TABLE II

LUNAR EARTH-POTENTIAL VARIATIONS FOR APPROXIMATE SYNODICAL PERIODS IN 1927

	0	1	2	3	4	5	6	7	8	9	10	11	U.C.
January	— 9	—19	—21	—19	— 9	— 9	— 8	—10	—18	— 8	— 6	+ 2	— 3
February	—12	—24	—15	—17	+ 1	— 2	+ 4	— 2	— 9	— 3	+14	+ 4	+ 7
March	—19	—30	—33	—61	—62	—34	—30	—24	— 1	+ 7	+19	+46	+42
April	+21	+56	+55	—51	—43	—41	—36	—39	—48	—50	—40	—28	—24
May	+ 1	—10	0	— 8	— 4	— 9	—28	—19	—23	—38	—34	—20	+46
June	—12	—13	—14	+ 7	+ 6	+10	+ 9	+20	+25	+31	+35	+35	+34
July	+ 1	+ 4	0	— 4	— 5	— 3	+ 1	— 7	— 1	+ 1	— 5	— 9	— 5
August	—20	—23	—21	—15	—16	—13	— 8	—13	— 5	— 3	0	+ 3	+ 8
September	—10	—33	—29	—35	—34	—31	—31	—38	—27	— 7	— 2	+10	+33
October	— 4	— 4	+12	+20	+21	+36	+41	+37	+47	+32	+21	+17	— 2
November	+ 8	+11	+ 2	+ 3	0	+11	+12	+13	+13	— 8	— 7	—12	— 5
December	— 8	—17	— 2	—12	— 3	— 2	— 4	—17	—11	— 3	— 6	+ 1	+ 9

	13	14	15	16	17	18	19	20	21	22	23	24
January	+ 7	+12	+ 9	+ 8	+13	+20	+11	+10	— 4	— 5	— 7	— 5
February	+18	+18	+14	+14	+ 8	— 5	— 9	—16	— 6	— 8	0	— 8
March	+44	+56	+54	+42	+39	+36	+12	+ 4	—22	—40	—27	—17
April	— 8	—15	— 4	+ 9	+ 6	+14	+21	+17	+23	+44	+56	+68
May	+23	+20	+13	+ 7	+ 7	+ 7	+15	+14	+15	+ 5	— 2	— 2
June	+18	+13	+13	+ 9	+11	— 1	—11	—34	—34	—34	—34	—23
July	+ 1	0	+ 3	— 1	+ 5	+ 9	+ 8	+ 6	+ 9	+ 8	+ 7	+ 6
August	+16	+21	+23	+29	+36	+28	+14	+ 9	— 1	—10	—12	—16
September	+33	+31	+48	+51	+48	+45	+30	+20	+19	— 2	—14	—24
October	—27	—43	—32	—31	—21	—18	—30	—27	—32	—27	—16	— 5
November	+18	— 2	— 8	—45	—40	—18	—11	—10	+14	+25	+27	+30
December	+16	+13	+ 6	+13	+ 8	+19	+17	+ 7	+ 8	— 2	—12	—13

The curves for the lunar periods are much more irregular than for the solar periods, due to the fact that while the lunar variation is only about one-fifth as great as the solar, the same irregular deflections enter into them.

The average lunar daily variation of earth potential for the year is shown in the dashed curve in Figure 1.

Seasonal variation of solar and lunar daily ranges.—Reference to Tables I and II will show that there is not only a solar and a lunar diurnal variation of electrometer deflection, but that in both cases there is also a seasonal variation of this daily range, so that the range is greatest at the equinoxes and least at the solstices. This variation is shown in Figure 2, where the average daily range for each month is shown. The lower curve represents the synodic monthly range of lunar daily variation and the upper curve represents the monthly range of daily solar variation.

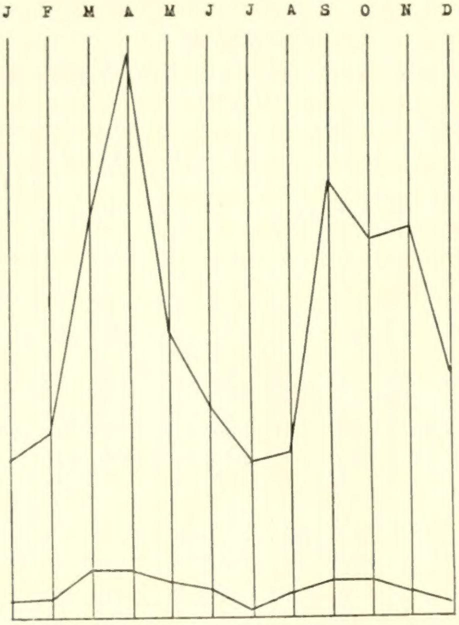

FIGURE 2

Average daily range of solar and lunar earth-potential variation for the different months of 1927. The upper curve represents the solar and the lower curve the lunar variation.

On the sign of the earth's charge.—In the conventional manner of treating electrical phenomena the earth has been regarded as an uncharged body, and the intensity of electrical charges upon other bodies has been measured by the difference of their electrical fields from the electrical field of the earth. This being the case, it would seem that the magnitude of the charge upon a perfectly insulated body in the earth's field might be changed by merely changing the magnitude or the distribution of the earth's charge. Thus the more positive the earth, the more negative the body, and *vice versa*. Also, if the earth's charge be negative, then displacing that charge away from the insulated body will make the charge of the body more negative, just as raising an insulated conductor above the earth causes it to become more electronegative to its surroundings.

In the records which have been published in previous volumes of this *Bulletin,* and in the foregoing pages of the present volume, the plus sign attached to electrometer deflections indicate that they are in the direction which they take when the metal electrometer case to which one quadrant pair is attached is given a positive charge. From the above considerations it would seem that when such a deflection takes place without a positive charge on the case and quadrants it indicates that the earth in the vicinity of the experiment has taken a *negative* charge.

Thus the curves indicate the distribution of the earth's charge at the given hours if that charge were positive, in which event the day side of the earth would seem to be less positive than the night side. On the other hand, if the charge of the earth be negative, as our reasoning would lead us to conclude, and as all the related phenomena indicate, then the day side of the earth is less negative than the night side. In that case, the *average* distribution of the variable part of the earth's charge around the parallel of 37–30′ N. is shown in the Bidlingmaier diagram in Figure 3.

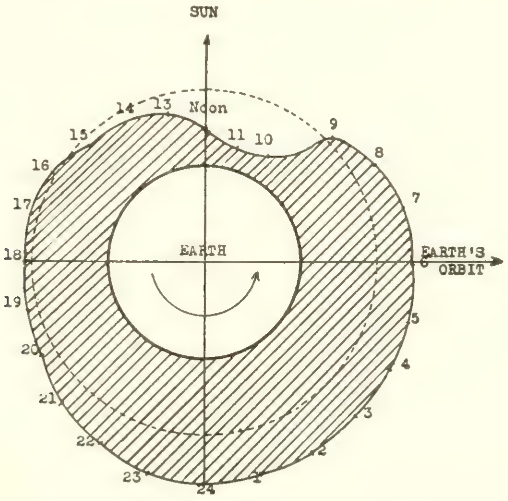

FIGURE 3

Diagram representing the average daily distribution of the variable charge of the earth around the parallel of latitude of Palo Alto for the year 1927.

Influence of solar disturbances upon the earth's charge.—As in previous years, the daily range of earth potential has been compared with the spottedness of the sun, but no new conclusions have been reached. It is evident that solar disturbances are often accompanied by disturbances in the range of earth-potential variation, but it is only occasionally that an electric disturbance upon the earth can be directly attributed to a given sun spot. In Figure 4 the three curves show the relation between total sun spottedness as published in *Monthly Weather Review* and the daily range of earth-potential variation and of average departure from the mean for the days of May, 1927. The continuous curve shows the total sun spottedness for each day of the month, the curve of short and heavy dashes shows the range of earth-potential variation for the respective days and the lower curve of longer

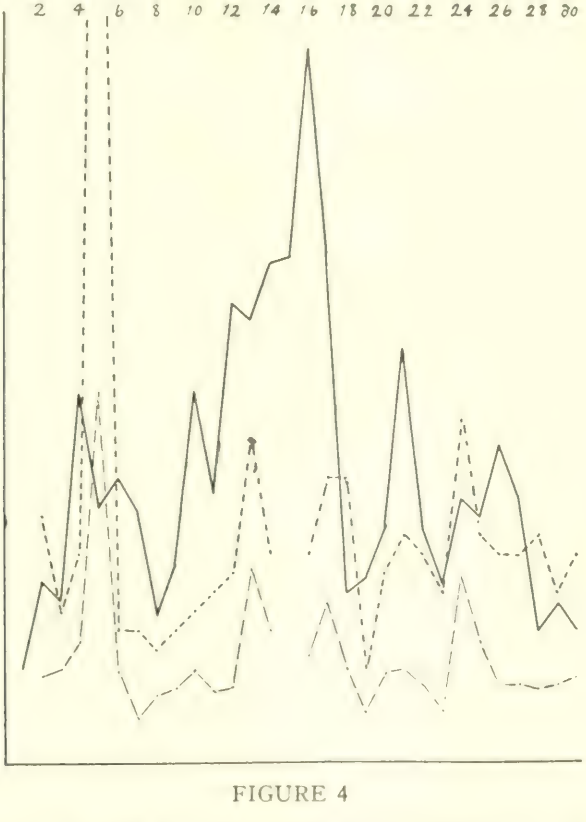

FIGURE 4

Comparison of the range of earth potential with the intensity of solar activity for the days of May, 1927. The continuous curve shows the total sun spottedness for each day of the month; the heavily dashed curve shows the range of earth-potential variation for the respective days; the lightly dashed curve shows the average departure from the 24-hour mean of the single hours of the respective days.

and lighter dashes shows the average departure from the mean for the 24 hours of the respective days. No record was obtained for May 15. On May 5 the range was nearly five times as great as the average for the month.

Effect of solar rotation upon the daily variation of earth potential.—There have been many attempts to show a permanent difference of solar activity on opposite sides of the sun. In *Astronomische Mitteilung,* **116,** 186, W. Brunner has arranged the daily sun-spot relative numbers in periods of 27 days each, corresponding to the sun-spot rotation period. The same has been done for the 337 daily ranges of earth-potential variation for the year 1927, taking care to give each day its proper position in its rotation period. The corresponding days of all periods have then been placed in vertical columns and their average range determined. The resulting numbers give the average diurnal variation range for one solar revolution in 1927. This average range is shown in Figure 5. It shows that the greatest daily ranges did occur when the same region of the sun was turned toward the earth. Thus, if we take the fourteenth day of our curve as representing the dividing line between two solar hemispheres, there were but two days above the average daily range on one side of it and seven days above the average on the other side of it. The three greatest ranges came within eight days of each other. Taken all together, the curve seems to indicate that for the year 1927 one solar hemisphere exerted a greater influence upon the daily range of earth-potential variation than did the other.

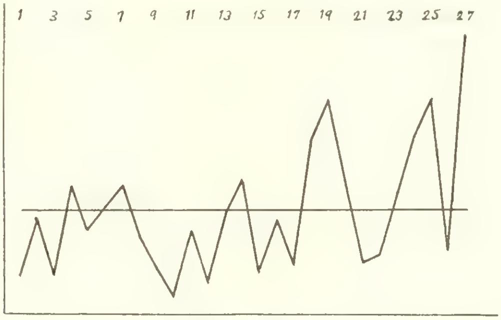

FIGURE 5

Average daily range of earth-potential variation for 337 days of 1927 arranged in periods of 27 days each to correspond with the rotational period of sun spots.

This variation in range was not due to a greater general range of variation, but to certain days of excessively great range. If these disturbed days are due to sun-spot activity, their tendency to recur after 27 days is readily accounted for.

Atmospheric ionization and the distribution of the earth's surface charge.—Care has been taken in previous numbers of this *Bulletin* not to mention the work of other investigators in a controversial manner, but the chief objections which have been raised to the validity of the conclusions which I have drawn have been based upon the assumption that the diurnal periodicity shown by my earth-potential curves is due to a diurnal variation in the conductivity of the air surrounding my apparatus, and although I have already shown the impossibility of this assumption (see especially Volume II, pp. 7–9) it seems worth while to take it up again and dispose of it permanently.

The particular investigation with which my work has been most often compared in justification of this contention is one entitled "Diurnal Periodicity of the Spontaneous Ionization of Air and Other Gases in Closed Vessels," which was carried on in the Cavendish Laboratory by Alexander Wood and Norman R. Campbell, and was published in *Philosophical Magazine*, 13, 265 (1907).

The apparatus used by Wood and Campbell is not figured in their paper, but reference is made to an article by Howard L. Bronson, in *Philosophical Magazine* of January, 1906, p. 143, in which is given a diagram of the apparatus after which theirs is patterned. The general arrangement of their apparatus as taken from Bronson's diagram and their description is given in the diagram in Figure 6, where it is compared with the apparatus which has been used by me.

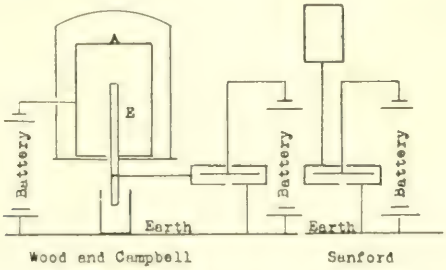

FIGURE 6

Diagram to illustrate electrometer connections of Wood and Campbell in recording "spontaneous ionization of gases in closed vessels" and of Sanford in recording earth-potential variations.

A is a closed metal vessel of capacity of six liters which stands on an insulated brass plate under a glass receiver. A long metal electrode, *E*, passes through the brass plate, from which it is insulated, into the metal vessel and extends to some distance outside. The external part is connected to one pair of quadrants of a quadrant electrometer, and the outer end projects into a beaker containing some uranium compound to ionize the surrounding air, thus allowing the electrode when charged to discharge into the air through a high resistance.

Vessel *A* is kept charged to a high potential by a storage battery, the other terminal of which is earthed. One quadrant pair of the electrometer is also connected to earth, as is one terminal of the battery by which the needle is charged.

As the gas inside vessel *A* becomes ionized, ions of the same sign as that of the charge on the vessel are repelled to electrode *E*, the charge upon which is slowly neutralized by leakage through the outer ionized air in the beaker. The potential to which *E* becomes charged depends upon the difference of the rates at which it receives and discharges ions. If we assume the potential of the earthed quadrants of the electrometer and the grounded battery terminals, as well as the ionization of the air in the beaker, to remain constant, any change in the deflection of the electrometer needle may be attributed to a change in the rate of ionization of the gas enclosed in *A*.

The authors found a periodic diurnal variation in their electrometer readings which was independent of the metal of vessel *A* and of the nature of the enclosed gas. They attributed this variation to a diurnal variation in the "spontaneous ionization" of the gas in *A*.

On pages 273–75 of their article the authors publish curves to show the close agreement of their curves for gaseous ionization with the Kew curves for diurnal variation of atmospheric potential gradient. At the time of publication of their paper the diurnal variation in the conductivity of the free air was not as well known as it is at present, but it even then seemed very improbable that the atmospheric potential gradient and the conductivity of the air increased together. In fact, it was generally believed, as has since been shown to be the case, that the two phenomena varied in *opposite* directions. G. C. Simpson, writing in *Nature* (**74**, 8) called attention to the improbability of Wood and Campbell's conclusions. He says:

> In discussing this problem it is usual to accept that there is a negative charge on the earth's surface and that the corresponding positive charge is a volume charge distributed in the atmosphere. Now all the measurements which we have of the daily variation of potential gradient have been made within a few meters of the earth's surface. Within these few meters there can be, relative to the charge on the earth, very little volume charge, so what our measurements actually refer to is the charge on the surface, the relation being $dv/dh = -4\pi\sigma$. The point to notice is that, with a given charge on the surface and a corresponding charge in the atmosphere above, the vertical distribution of the charge and the conducting state of the upper atmosphere do not in the slightest affect the potential gradient within a few meters of the surface. If the potential gradient changes there it can only be by a change in the surface charge of the earth.

Simpson then calls attention to the fact that if there is a penetrating radiation which has a diurnal variation, the air at all heights should have its ionization increased at the same time and the air near the surface should at these times become more conducting, and the potential gradient should *decrease* instead of *increase* as it does with Wood and Campbell's times of increased conductivity.

Other measurements made at about this time to determine the conductivity of the air in closed metal vessels failed to show a regular diurnal variation, especially the experiments of C. S. Wright, *Philosophical Magazine*, 17, 295-318 (1909), where a gold leaf electroscope disconnected from the earth was used to measure the rate of leakage through the air.

A comparison of Wood and Campbell's curves with those given by my own apparatus made it seem virtually certain that we had both been recording the same phenomenon, and so long as their explanation of the cause of the electrometer variation was accepted as the true one, it seemed impossible to doubt that the electrometer deflections which I had been recording were due in some manner to changes in atmospheric conductivity. It is for this reason that it seems important to consider the two explanations together.

Since in both cases the diurnal variation which was recorded was different at different times of year, I have chosen corresponding months for comparison. In Figure 7 the continuous curve represents the mean of Wood and Campbell's curves for the months of March and April, 1906. The dashed curve represents the mean diurnal variation of earth potential at Palo Alto for March and April, 1927. The two curves indicate that not only was the same phenomenon being recorded in the two instances, but that its daily variation was nearly the same at Cambridge and Palo Alto.

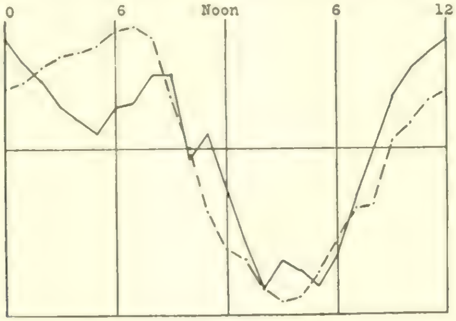

FIGURE 7

Comparison of Wood and Campbell's curves for the ionization of gases in closed vessels for the months of March and April, 1906, with Sanford's curves for daily variation of earth potential for March and April, 1927. The continuous curve gives the average of Wood and Campbell's curves and the dashed curve gives the average of Sanford's curves.

The similarity of the set-up in the two investigations suggests that there should be a close relation in their results, and the arrangement of my own apparatus makes it possible to decide definitely whether the diurnal variation of the electrometer deflection is due to atmospheric ionization or to a change in the surface charge of the earth. The diagram in Figure 6 may indicate the essential parts of the two sets of apparatus. In the Wood and Campbell apparatus one pair of quadrants is earthed and the other pair is charged from the electrode which enters the charged vessel. In my apparatus one pair of quadrants is earthed and the other pair is connected to an insulated conductor, the whole apparatus being inside a closed, hollow conductor which is thoroughly grounded. The charge on the insulated conductor cannot be increased or decreased by any charge on the enclosing hollow conductor, and it is discharged to this outer conductor at the beginning of the investigation. Since the only charged body inside this hollow conductor is the electrometer needle, the only charge which the insulated quadrants and the connected conductor can acquire is by leakage from the electrometer needle. The rate of this leakage may vary with a change in the ionization of the surrounding air, and if there is a daily variation in the conductivity of the air inside the electrometer case there should be a diurnal variation in the electrometer deflection, and the two sets of apparatus should indicate such a change in the same manner.

As is shown in Figure 7, they do indicate a similar diurnal variation in the potential difference between the two quadrant pairs.

In the case of the Wood-Campbell apparatus, if the charge on vessel *A* is kept constant while the charge on their electrometer needle is reversed in sign, the deflection of the electrometer needle due to a leakage of charge from *A* to electrode *E* will be reversed in direction, but if both vessel *A* and the electrometer needle have their charges reversed in sign at the same time, the electrometer deflection due to a leakage of charge from *A* will not be reversed in direction. If, after reversing the sign of the charge on both, the direction of the daily variation in electrometer deflection should reverse, the daily variation must be due to a change of charge on the earthed quadrants.

In my own apparatus, since the insulated quadrants can be charged only by leakage from the electrometer needle, the sign of their charge must always be the same as the sign of the needle charge. The electrometer needle must always be deflected away from the insulated quadrants as soon as they become charged, no matter what the sign of this charge. Hence, reversing the sign of the needle charge will not reverse the direction of deflection due to a leakage charge on the insulated quadrants. *A change of sign of the needle charge will not change the direction of deflection due to a given change in the ionization of the air.*

If the electrometer deflection is due to a change in the surface charge of the earth, and hence to a change in charge of the earthed quadrants, a change in sign of the needle charge *will* change the direction of deflection of the needle due to a given change on the earthed quadrants.

Reversing the sign of the charge upon my electrometer needle does reverse the direction of the periodic daily deflection. It is my present custom to reverse the sign of the charge on my electrometer needle at the beginning of each month, and my records for succeeding months are accordingly measured in opposite direction on my record sheets. By this method any irreversible variation, such as may be caused by temperature or atmospheric ionization will be neutralized when a long series of records are combined.

It seems necessarily to follow from these considerations that the diurnal variation in electrometer deflection which was observed by Wood and Campbell was due to the same cause as the diurnal variations which I have been recording for the past six years, and that this cause is the distribution of the surface charge of the earth relative to the sun. A still further proof of this may be shown in the consideration of other investigations which have been made on atmospheric ionization.

In *Physikalische Zeitschrift*, 27, 755–61 (1926) is an article by Fraeulein Doctor Rose Stoppel, entitled "Beitrag zum Problem der Leitfaehigkeit der Atmosphaere," in which the author shows what seems to be a diurnal variation of the conductivity of the air in a closed room at constant temperature. This variation is shown to be independent of light, temperature, moisture, or atmospheric pressure, and it has a similar daily range in Akureyri, Iceland, in midsummer that it has in Hamburg in midwinter, so it is not dependent upon the relative length of day and night. The author concludes that it must depend upon some cosmic phenomenon.

The close relation between Dr. Stoppel's curves and the curves representing the daily variation of the earth's surface charge at Palo Alto suggests that there may be a physical relation between the phenomena which they represent. This correspondence between the two sets of curves may be seen by inspection of Figure 8, in which the continuous curve represents the

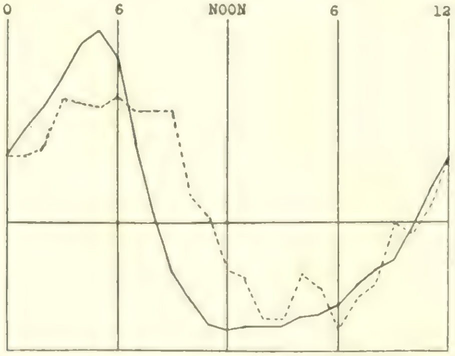

FIGURE 8

The continuous curve represents the average of eight days of Dr. Stoppel's curves of atmospheric conductivity at Hamburg and the dashed curve represents the average of Sanford's curves of earth potential at Palo Alto for the same eight days.

average of the eight daily curves (October 29–November 5) shown in *Kurve 5,* page 758, of Dr. Stoppel's paper and the dashed curve represents the average variation in the intensity of the earth's surface charge at Palo Alto for the same eight days.

The comparison of Dr. Stoppel's Iceland curves with my own do not show so close a resemblance, though the relation is still evident. In Figure 9 the continuous curve represents the daily average of Dr. Stoppel's curves for eight days (August 20–27, 1925) at Akureyri, Iceland, and the dashed curve gives the average of my electrometer records for August 20, 21, 22, 24, 25, 28, 1925. August 23, 26, and 27 are missing from my records.

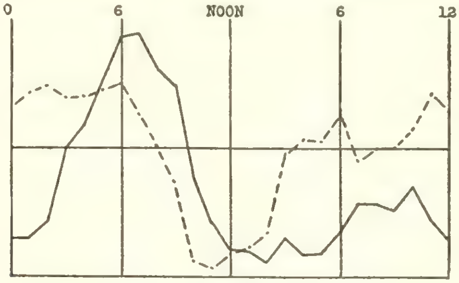

FIGURE 9

The continuous curve represents the average of eight days of Dr. Stoppel's curves of atmospheric conductivity at Akureyri, Iceland, and the dashed curve represents the average of Sanford's curves of earth-potential variation for six days of the same period.

In the case of Dr. Stoppel's other curves my records are incomplete, but as far as they go the agreement is about as close as in the two here given.

The reason for selecting Dr. Stoppel's curves for comparison with my own is because her arrangement of apparatus for measuring atmospheric conductivity was different from that of Wood and Campbell, and because the opportunity appeared of deciding definitely whether she was measuring atmospheric conductivity or earth-potential variation.

In Figure 10 is given a diagram which may aid in describing Dr. Stoppel's arrangement of apparatus. A Benndorf recording electrometer was

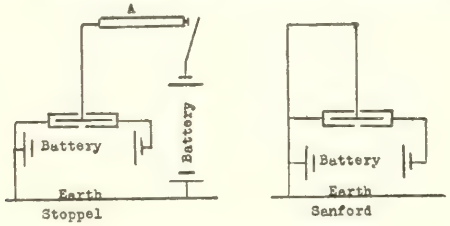

FIGURE 10

Diagram to illustrate Stoppel's and Sanford's electrometer connections.

used, the two quadrant pairs of which were kept at a constant potential difference (usually 100 volts) by a constant battery, one pole of which and one quadrant pair were earthed. The electrometer needle was connected to an insulated conductor, *A* in the diagram, which was automatically charged to a potential of 200 volts every half hour by a switch which was regulated by a clock. Between the times of charging, the switch was left open and the charge leaked off from this conductor and the connected electrometer needle to the surrounding air, and the needle deflections due to this leakage were recorded every two minutes by the electrometer mechanism.

The battery by which the insulated conductor and needle were charged had one terminal connected to earth. The potential difference between the battery terminals was taken as the potential to which the needle and conductor *A* were charged at the beginning of a half-hour period. The position of the electrometer needle when discharged was determined at the beginning of a series of records, and the potential of the lowest point reached in each half-hour interval was measured from this zero.

Arranged in this manner, Dr. Stoppel's electrometer recorded a periodic daily variation which was so similar to that recorded by my own apparatus on the same days that there can be small room for doubt that they are due to the same physical cause.

In the case of the arrangement of Dr. Stoppel's apparatus, such a variation might be produced by either a daily change in atmospheric conductivity or a daily change in the intensity of the earth's surface charge. While we may not know how to exclude the second possibility, it is very easy to eliminate the first. All that is necessary is to remove the charged body *A* and to connect the electrometer needle to earth, as is indicated in the second diagram in Figure 10. We then have an electrometer with one pair of quadrants and the needle connected to earth (or, in the case of my experiment, to the inside of an earthed wire cage) and the other pair of quadrants kept at a constant potential difference from the grounded pair. No part of the apparatus can acquire and hold any charge from the surrounding air.

For the past two months (February and March, 1928) an electrometer set up in this way has been standing on the same pier and recording upon the same sheet as the one which has been used for measuring the earth-potential variation for the past six years. Figure 11 shows the comparison of their average variations for thirty days of March, 1928. The continuous curve gives the average record of the electrometer set-up as shown in the diagram in Figure 6, and as it has hitherto been used, and the dashed curve gives the record of the one set up as in Figure 10, in which all possible effects of air conductivity seem eliminated.*

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* Since the above was written Dr. Stoppel, to whom my results were communicated, writes me that she has repeated the experiment with the same results that I have obtained.

As may be seen, the two curves, while similar, are not identical. The new method (represented by the dashed curve) gives a much smoother record than does the old method, which indicates that it is less liable to local disturbances, of whatever nature. It is also much more sensitive than the older method to changes in the electrical condition of the earth. By subtracting this curve from the continuous one, whatever effects of atmospheric conductivity there are in the latter should appear in their algebraic difference.

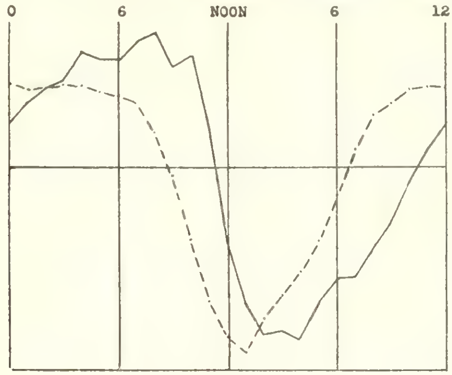

FIGURE 11

The continuous curve shows the average daily variation of earth potential for thirty days of March, 1928, with the electrometer connected as in Figure 6, and the dashed curve shows the average daily variation for the same days with the electrometer connected as in Figure 10.

This difference is shown in the continuous curve in Figure 12, where it is compared with the curve of daily variation of electrical conductivity of

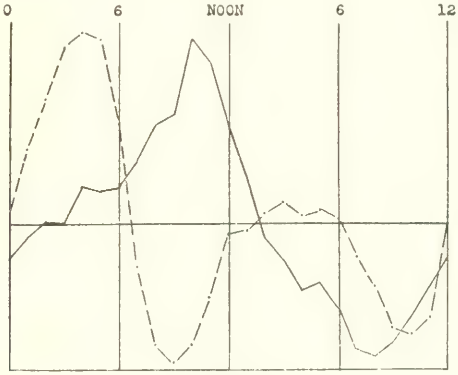

FIGURE 12

Algebraic difference of the curves in Figure 11 compared with the curve for daily variation of atmospheric conductivity at Potsdam. The continuous curve represents the difference of the two curves in Figure 11.

the air at Potsdam for the years 1910–11, as given in Kähler's *Luftelektricitat*, p. 66. The two curves are strikingly unlike, the high maximum of conductivity at 4:00 A.M., which is a conspicuous feature of air-conductivity curves in general, being wholly absent in the resultant curve and there being only one daily maximum and minimum, instead of the two which are commonly shown in air-conductivity curves.

The agreement with the curve for the daily variation of atmospheric potential gradient for the month of March is much closer, though it seems improbable that there should be a potential gradient inside a wire cage in a closed room.

Whatever the explanation of the difference of the two curves in Figure 11, it plainly is not due to atmospheric conductivity. It also seems necessary to recognize that not all of the curves supposed to indicate the daily variation of atmospheric conductivity are really concerned with that phenomenon.

A second new method of recording the changes in distribution of the earth's negative charge.—Since the material for this number of the *Bulletin* was made ready for the press, a still more sensitive method of recording the variation in distribution of the earth's charge, and one which seems to be free from all the theoretical objections which have been made to previous methods, has been devised.

A quadrant electrometer (by Guenther-Tegetmeier) had one diagonal pair of quadrants removed, the remaining pair discharged to earth and insulated on amber supports wholly inside the heavy metal case of the instrument, and the needle and metal case of the instrument grounded to the inside of an earthed wire cage.

With this arrangement, in which no battery or artificial charge appears, the grounded needle goes through a daily oscillation of approximately 8 degrees of arc, which oscillation is not due to changes in temperature, barometric pressure, or atmospheric changes of any known kind. The range of deflection varies from day to day, and is of a magnitude which would require for its production the introduction of a battery of from 75 to 100 volts between the needle and the insulated quadrants.*

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* Since the copy for this paper was in the hands of the printer the phenomenon of the variation of the earth's surface charge has been shown in a still more striking manner. Instead of connecting the electrometer needle to earth, as described above, its metal suspension is connected to the quadrant pair and both are insulated on amber supports inside a tightly closed metal case which is inside of and connected to the outside wire cage. In this case both the needle and the quadrants must remain at a common potential. When they become either electropositive or electronegative relative to the earth the needle is repelled by the quadrants, hence it gives a double deflection in twenty-four hours.

The range of these daily deflections are as great as are produced by charging the instrument to a potential of plus or minus more than one hundred and fifty volts relative to the earth.

It is evident that an electrostatic field of this range of variation in intensity is developed between the earthed needle and the insulated quadrants every 24 hours. In the production of this variation all known agencies except the electrostatic induction of the sun's negative charge would seem to be excluded, and the evidence seems to strongly indicate, if not to definitely establish, that both the earth and the sun are seats of enormous negative electric charges which are sufficiently great to mutually react to each other's inductive influence across the millions of miles which separate them. This being true, there is no need of looking further for an explanation of their respective magnetic fields.

Many other phenomena hitherto regarded as incapable of explanation are made much clearer by this conclusion. As one example, consider the solar attraction of the comet's "beard" and the solar repulsion of the comet's tail. Certainly, both of these cannot be explained as due to radiation pressure. Newcomb,* speaking of Zöllner's attempt to explain these phenomena by electric forces says:

> The various papers in which he has elaborated his views of the constitution of comets are marked by profound research; and we must regard his theories as those which, on the whole, most completely explain all the phenomena. But they still lack the one thing needful to secure their reception: there is no evidence that the sun acts as an electrified body; and until such evidence is adduced by experiment, or by observation on other bodies than comets, the electric theory of the comet's tail can only be regarded as a more or less probable hypothesis.

The evidence which Newcomb regarded as essential to the establishment of the electrical nature of the comet's tail has now been furnished in two different ways. Hale has established the existence of enormous electric fields over sun-spot areas, and the present investigation has made it virtually certain that such electric fields are not confined to sun-spot regions, but that the whole surface of the sun is charged to a negative potential of millions of millions of volts as compared with interstellar space.

The persistence of negative charges on the sun and the earth.—It is gradually coming to be recognized that the earth has a persistent electrical field, both upon its surface and in the higher atmosphere, and there have been a number of recent attempts to explain the existence of this electric field on the basis of some hypothetical phenomenon which is, in nearly every case, impossible of observation.† This habit of explaining the known in terms of the unknown seems to be gaining in popularity, and while it may be philosophic it is certainly as far as possible from being scientific.

The question as to how a negatively electrified body may hold its charge has never been answered to the satisfaction of most physicists. It is a very old question, and occupied much more space in the discussions of one hundred years ago than it does at the present time. The present writer proposed an explanation in 1911* which may be very briefly outlined here.

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* *Popular Astronomy,* 3d. ed., p. 410.

† See especially Wilhelm Anderson in *Zeitschrift für Physik,* **44,** 376 (August, 1927).

In the present state of our knowledge we are compelled to explain any stress between two bodies as due in some way to an intervening medium. The only other alternative is the acceptance of the notion of "force at a distance," which acceptance is equivalent to a confession of failure to carry the explanation any farther. From the very nature of the concept, force at a distance must remain forever incomprehensible. If we are to *explain* the phenomena of electric attraction and repulsion, it must be by means of some medium which pervades all space in which these phenomena may occur. Since Maxwell's identification of the Faraday Medium with the Luminiferous Ether, this medium has been accepted as the seat of all electric phenomena.

Larmor, in *Aether and Matter,* p. 26, says:

> According to any aether theory static electric attraction must be conveyed by elastic action across the aether and an electric field must be a field of strain: hence each sub-atom with its permanent charge must be surrounded by a field of permanent or intrinsic aetherial strain, which implies elastic quality in the aether instead of complete fluidity.

It is a characteristic of elastic bodies that they react to any strain in such a manner as to distribute the strain as uniformly as possible throughout the whole body. Accordingly, if electrons act as centers of strain of any kind (either compressional or distortional) in the ether, and if they are at the same time free to move through the ether, the elastic reaction of the ether to this strain will tend to distribute the electrons as uniformly as possible throughout the whole body of the ether. Thus, if the ether of the universe were everywhere of uniform elasticity, so that its reaction to electrostatic strain would be everywhere the same, there would be no isolated electric charges in the universe: the electrons of the universe would be uniformly spaced everywhere.

It is plain that if there were inelastic regions in the ether, regions where there could be no elastic reaction to an electric strain, all the electrons in the universe would ultimately be gathered into those regions. All the electrons in the boundaries of such regions would be driven into them by the elastic reaction of the surrounding ether, and once inside these inelastic regions there would be no outward force exerted upon them.

In a similar manner, regions in the ether of less than the normal electric elasticity of that medium would collect an excess of electrons until the greater electric strain within these regions would induce a sufficiently great elastic reaction to balance that of the outside ether where the electrons were fewer.

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* *A Physical Theory of Electrification,* Leland Stanford Junior University Publications, Stanford University, California.

Maxwell identified the electric elasticity of the ether within material bodies with the reciprocal of the specific inductive capacity of the respective bodies: i.e., the higher the specific inductive capacity of a body the weaker will be the elastic reaction of the ether within that body to a given electric strain.

It is well known that the specific inductive capacity of all material bodies is greater than that of the free ether, and we find most of the electrons which we can identify gathered into material bodies.

Since the physical universe is filled with bodies containing electrons, the ether pervading the whole physical universe must be in a state of electric strain. When the electric strain about a material body is the same as that of the ether of space, the body may be said to be unelectrified. When the electric strain about a material body is either greater or less than that of the ether of space the body is surrounded by a region called an electric field, in which region electrons are impelled from or toward the electrified body. If the electric strain about the body is less than that of the ether of space the body is said to be positively electrified, and the electrons in the more highly strained regions of the ether may be impelled into it. If the electric strain about the body is greater than in the free ether of space the body is said to be negatively electrified, and outside electrons will be repelled by the elastic reaction of its electric field.

Any excess of electrons in a body will increase the elastic reaction of the outside ether to the electrons on its surface. As long as this reaction is greater in the outside ether than it is in the ether within the body electrons will be held to the body by the surrounding ether.

In the artificial vacua which we can produce we know that the insulating efficiency of the ether in the rarefied gas is very great, but we have no knowledge of the force required to drive an electron out of a conductor against the elastic reaction of the ether of free space.

Here upon the earth we do not compare the elastic reaction to electric strain with that of the ether of space, but with that of the ether in the earth's atmosphere. We call a body negatively electrified when if put into electrical communication with uninsulated bodies upon the earth it will lose electrons to them, and positively electrified when under similar conditions it will acquire electrons. If the electric charge of the earth were greater, a body which we now class as negatively electrified might be classed as positively electrified.

Since we have no means of knowing the electric elasticity of the ether in the interstellar spaces it is idle to speculate on how great a negative charge can be retained upon a planet, or a star.

There seems to be a consensus of opinion among the physicists who have written on the subject that the persistence of an electric charge upon the sun is not only more difficult to explain than in the case of a solid body like the earth, but most of them seem ready to pronounce such a phenomenon impossible. This latter assumption seems to be based wholly upon intuition: since no one seems to know how a negative charge may be held on any body, there seems but slight grounds for inferring either that it may, or may not, be retained upon the sun.

Most of the arguments against the possibility of an electrified sun are based upon the gaseous condition of that body, but since no one has lived upon or experimented with an incandescent gaseous globe in a vacuum we can only speculate upon the electrical conditions on such a body.

The hypothesis which has most frequently been proposed is that electrons or charged ions of any kind can be held to the sun only by gravitation, though it is well known that electric charges are not held to bodies on the earth by gravitation, or by any other force acting between electrons and the atoms of a body. Nowhere does the electric capacity of a body depend upon its mass. Still, Lindemann* has undertaken to show that a hydrogen ion cannot be held to the sun against an electric repulsion of 1,980 volts, and Wilhelm Anderson† has recently calculated that electrons would be expelled from the sun if that body were charged to a negative potential of 1.06 volts.

Nevertheless, it is well known that negative potentials of many millions of volts have persisted for many months at a time over solar regions of many times the area of the earth's surface.

In spite of his belief in the impossibility of an electrified sun, Wilhelm Anderson has convinced himself and many others (including the present writer) that the solar corona is largely made up of an electron atmosphere.

One very potent agency in preventing the escape of electrons from the sun, and one which is usually ignored, is the sun's magnetic field. The fastest known particles projected by radio-active atoms across the sun's magnetic force lines would be curved into orbits of but a few meters' radius, and such electrons could leave the solar surface only along the magnetic force lines. Hence, whenever a solar eclipse occurs at times of sun-spot minimum we see them escaping from the sun's polar regions, where the magnetic force lines are vertical to the surface, and accumulating over equatorial regions where the force lines are parallel with the surface. Also, at times of sun-spot maximum we see them shooting out to great distances from the sun along the magnetic axes of powerful sun spots.

Since we know nothing of the electric elasticity of the ether either outside or within the sun's photosphere or corona, we cannot know how the one differs from the other. We can only know that if it is the elastic reaction of the ether which helps to retain the electric charge of the sun it is ample for that purpose, and we do know that no other efficient cause for its persistence has ever been proposed. We have no *a priori* grounds for passing upon the possibility or impossibility of the electrification of the sun. We know only that whatever exists is possible.

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* *Philosophical Magazine*, 38, 669 (December, 1919).

† *Zeitschrift für Physik*, 43, 594.

Daily variations in atmospheric potential gradient.—During the year 1927 the daily variations in atmospheric potential gradient were recorded for 332 days. The method used was the same as in 1926. Two insulated copper balls, one seven inches and the other eight inches in diameter, were raised above the roof of the observatory building, one being three meters higher than the other. The surfaces of the balls were enameled, and their suspension and conducting wires were insulated.

Wires from the balls led to the separate quadrant pairs of a quadrant electrometer, the needle of which was charged by a battery of dry cells. The purpose of this arrangement is to prevent, as far as possible, the collection of charged ions from the air. The average daily variation between the two balls is given in terms of electrometer deflection in Table III. A deflection

TABLE III

MONTHLY AVERAGES OF DAILY VARIATION OF AIR-POTENTIAL GRADIENT FOR THE YEAR 1927

A.M.	1	2	3	4	5	6	7	8	9	10	11	12
January....	—10	— 9	—11	— 7	—10	— 8	— 8	— 7	— 15	— 13	— 1	+18
February..	—23	—27	—31	—30	—32	—32	—28	— 34	— 41	— 10	+ 10	+40
March.....	—20	—33	—28	—41	—47	—55	—50	— 75	—114	—111	— 60	+ 5
April......	+48	+35	+24	+11	+11	0	—52	— 87	—120	—143	—122	—85
May.......	+33	+13	— 4	—17	—31	—39	—98	—140	—150	—146	—104	—52
June.......	+55	+33	+18	+22	+13	—38	—70	—120	—153	—149	—116	—80
July.......	+31	+10	— 2	+ 2	—10	+12	— 4	— 60	—108	—138	—121	—87
August....	+36	+30	+27	+26	+25	+33	+27	— 14	— 54	—102	— 99	—90
September.	+39	+18	+16	+11	+ 2	— 1	—11	— 23	— 47	— 60	— 51	—44
October....	+30	+30	+36	+45	+41	+39	+34	+ 19	+ 3	— 47	— 58	—61
November..	— 6	+ 2	+12	+ 4	+ 4	0	— 5	— 2	— 22	— 31	— 18	—16
December..	—21	—22	—10	— 9	—14	—13	— 9	— 12	— 26	— 19	+ 8	+22

P.M.	1	2	3	4	5	6	7	8	9	10	11	12
January....	+23	+24	+21	+17	+15	+11	0	+ 2	— 5	— 7	— 6	— 8
February..	+50	+50	+47	+36	+33	+28	+16	+ 4	— 8	— 13	—15	—18
March.....	+44	+67	+75	+68	+65	+74	+76	+ 67	+ 42	+ 29	+ 7	— 9
April......	—42	—10	+ 8	+15	+45	+39	+44	+ 53	+ 64	+ 65	+72	+57
May.......	—18	+16	+32	+58	+73	+73	+72	+ 98	+ 96	+ 77	+71	+53
June.......	—49	—18	+ 6	+16	+31	+50	+61	+101	+107	+ 93	+77	+59
July.......	—61	—29	—14	— 7	+ 3	+18	+43	+122	+137	+112	+99	+70
August....	—72	—61	—51	—49	—46	—23	+40	+ 92	+ 80	+ 68	+48	+36
September.	—47	—42	—37	—42	—44	—16	+21	+ 58	+ 65	+ 62	+63	+56
October....	—71	—67	—62	—64	—70	—15	+15	+ 32	+ 36	+ 34	+34	+22
November..	— 2	+ 1	— 6	—10	—4	+15	+27	+ 23	+ 8	+ 14	+14	0
December..	+29	+29	+16	+12	+14	+17	+14	+ 8	+ 5	— 5	— 4	—15

in the + direction means an increase in the positive charge of the higher ball with reference to the lower. The average daily variation for the year is shown graphically in Figure 13.

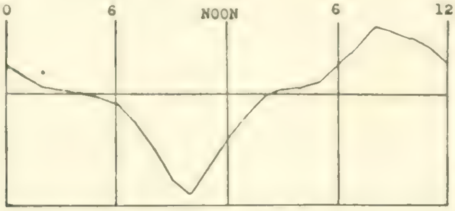

FIGURE 13

Average diurnal range of atmospheric potential gradient for 1927.

A comparison of this curve with that for the diurnal variation of the earth's surface charge shows that while they are very similar they are not identical. Since Figure 1 indicated the general distribution of the *negative* charge of the earth around the parallel of latitude of Palo Alto, while Figure 13 indicates the distribution of the *positive* potential gradient around the same parallel, they should agree if the atmospheric potential gradient is wholly due to the induction of the earth's charge and if the conditions in the surrounding air were uniform in regard to its dielectric properties. However, we know that these conditions are not everywhere the same. Both the specific inductive capacity and the electrical conductivity of the air varies with its composition, with its density, and with the time of day.

It is now well known that an increase in the conductivity of the air causes a decrease in the atmospheric potential gradient, and that the product of these quantities gives what is known as the air-earth current. This product may also be regarded as a potential gradient which has been corrected for atmospheric conductivity, and it, rather than the observed potential gradient, should be compared with the distribution of the earth's negative charge.

There is one respect in which the records of this observatory show a marked difference between the daily range of earth potential and of the potential gradient in the air. As is shown in Figure 2, the daily range of earth-potential gradient was greatest at the equinoxes and least at the solstices, while the daily range of air potential is greatest at the summer solstice and least at the winter solstice.